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Meson-Baryon coupling constants in QCD sum rules

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CHAPTER 1

Introduction

Hadronic interactions are in principle explained by quantum chromodynamics (QCD), which is the theory of strong interactions. QCD provides a description of the hadronic states and the processes based on the dynamics of the quarks and the gluons. It is, however, realized that such first-principle description of the hadron-hadron interaction is highly complicated, particularly at low energy, and thus approaches adapting effective hadronic Lagrangians are quite useful. The coupling constants at hadronic vertices are therefore one of the most fundamental quantities that should be computed directly from QCD.

There are very successful approaches in explaining the nucleon-nucleon (NN) [1, 2], hyperon-nucleon (YN) [3–5] and hyperon-hyperon (YY) interactions in terms of One Boson Exchange (OBE) models, based on Regge-pole theory [6, 7]. The main idea is that the interaction of two baryons can be completely explained with one meson exchanges. The interaction mechanism can be extended beyond one-meson exchanges to e.g. two-meson exchanges, however OBE has been reasonably successful in describing the complete interaction. These phenomenological potential models provide a very accurate description of the rich nucleon-

nucleon (NN) and the more scarce hyperon-nucleon (YN) scattering data. In these models, the values of the meson-baryon coupling constants are empirically determined so as to reproduce the NN and YN interactions. The $SU(3)$ -flavor symmetry is used for the coupling constants, whereas the $SU(3)$ -breaking is introduced by several factors like the baryon and meson masses, meson-mixings within the meson-nonet and the charge-symmetry breaking (CSB) due to $\Lambda - \Sigma^0$ mixing.

The OBE models include the following meson exchanges:

- (i) The pseudoscalar-mesons (π, η, η', K).
- (ii) The vector-mesons (ρ, ω, ϕ, K^*).
- (iii) The scalar-mesons (a_0, σ, f_0, κ).
- (iv) The pomeron P and the tensor-mesons (f_2, f'_2, a_2).

Calculation of the coupling constants at the hadronic vertices directly from the QCD is a long-standing problem. QCD has been very successful in the large momentum transfer regime where the quark-gluon coupling constant is small and one can reliably apply perturbative methods. However, at the hadron scale the quark-gluon coupling constant is of order unity and perturbation theory fails. In this regime one should use some non-perturbative methods. Among other approaches, the QCD Sum Rules (QCDSR) method [8–10] has proven to be a powerful tool to extract qualitative and quantitative information about hadron properties [11, 12]. The QCDSR have well-known advantages and the method has been extensively applied to hadron phenomenology. The main idea behind QCDSR is to link the hadronic degrees of freedom with the underlying QCD parameters. In this framework, one starts with a correlation function that is constructed in terms of hadron interpolating fields, appropriately chosen according to the quantum numbers of the hadrons in question. On the theoretical side, the correlation function is calculated using the Operator Product Expansion (OPE) in the Euclidian region. This consists of expanding the correlation function in terms of some local operators and Wilson coefficients. The correlation function is matched to a sum over hadronic states via a dispersion relation. The matching provides a determination of hadronic parameters like baryon masses, magnetic moments and coupling constants of hadrons.

Our aim in this work is to calculate the meson-baryon coupling constants

using the method of QCDSR. There are different approaches in constructing the sum rules. The most convenient one for our purposes is the external-field QCDSR method. Our motivation is to define the coupling constants in terms of QCD parameters which will give us a deeper understanding of the mechanism behind the interactions of two baryon systems in terms of the OBE model. In this framework, we consider the *vacuum-to-vacuum* transition matrix element of two baryon interpolating fields in an external meson field [13] and calculate the coupling constants of scalar, vector and pseudoscalar mesons to the baryons. One of the advantages of this approach is that it is consistent with the SU(3)-flavor symmetry [14], as we will extensively show in the following chapters, so that the $\alpha = F/(F + D)$ ratios of the meson octets can be determined in a model-independent way. The method allows, as well, to estimate the amount of SU(3)-breaking in the couplings, which occurs as a result of the *s*-quark mass and the physical masses of the mesons and baryons. This approach provides a very convenient ground for us to compare our results with the ones from the phenomenological potential models. We will compare our results for the coupling constants with those from a model of the *NN* and *YN* interaction, the Nijmegen soft-core potential [2, 4, 5, 15, 16].

The work is organized as follows: In Chapter 2 we give a brief introduction to QCD and the method of QCDSR. We present how the sum rules are constructed by matching the hadronic degrees of freedom on the phenomenological side and quark-gluon degrees of freedom on the theoretical side, where we take the nucleon mass sum rule as an example. Also in this chapter, we remind the reader how the meson-baryon interaction Lagrangians are constructed starting from the meson and baryon SU(3) multiplets.

In Chapter 3, we use the external-field QCDSR method to evaluate the coupling constants of the light isoscalar-scalar meson (“ σ ” or ϵ) to the Σ , Ξ , and Λ baryons. We evaluate the correlation function of the baryon interpolating fields in the presence of an external constant isoscalar-scalar field σ and construct the sum rules. We assume ideal-mixing and make the analysis in both the $q\bar{q}$ and the $q^2\bar{q}^2$ pictures for the scalar mesons. We show that the coupling constants as calculated from QCDSR are consistent with SU(3) flavor relations, which leads to a determination of the $F/(F + D)$ ratio of the scalar octet, α_s , assuming ideal-mixing.

The coupling constants with SU(3)-breaking effects are also discussed.

Chapter 4 is devoted to the calculation of the vector and the tensor coupling constants of the vector mesons ρ and ω to the N, Λ , Ξ and Σ baryons using the external-field QCDSR method. For this purpose, we define a constant background tensor-field in order to take account of both the vector and the tensor coupling. We obtain the $F/(F + D)$ ratio of the vector-octet where we assume ideal-mixing for the isoscalar members and discuss the SU(3)-breaking effects as well.

In Chapter 5, we explore the earlier studies of the pion-nucleon coupling constant with the method of external-field QCDSR. In the literature, one encounters two schemes for the pion-nucleon coupling constant: the pseudoscalar coupling and the pseudovector coupling. These two schemes are related to each other with a Goldberger-Treiman relation however their calculations are independent. We show how the pseudoscalar and the pseudovector couplings of the nucleon can be calculated from QCDSR and we extend these calculations to the axial couplings of the Delta-baryon. Finally, we arrive at our conclusions in Chapter 6, where we summarize our work.